Mean Global Precipitation and Error Estimates: GPCP, TRMM and Cloudsat

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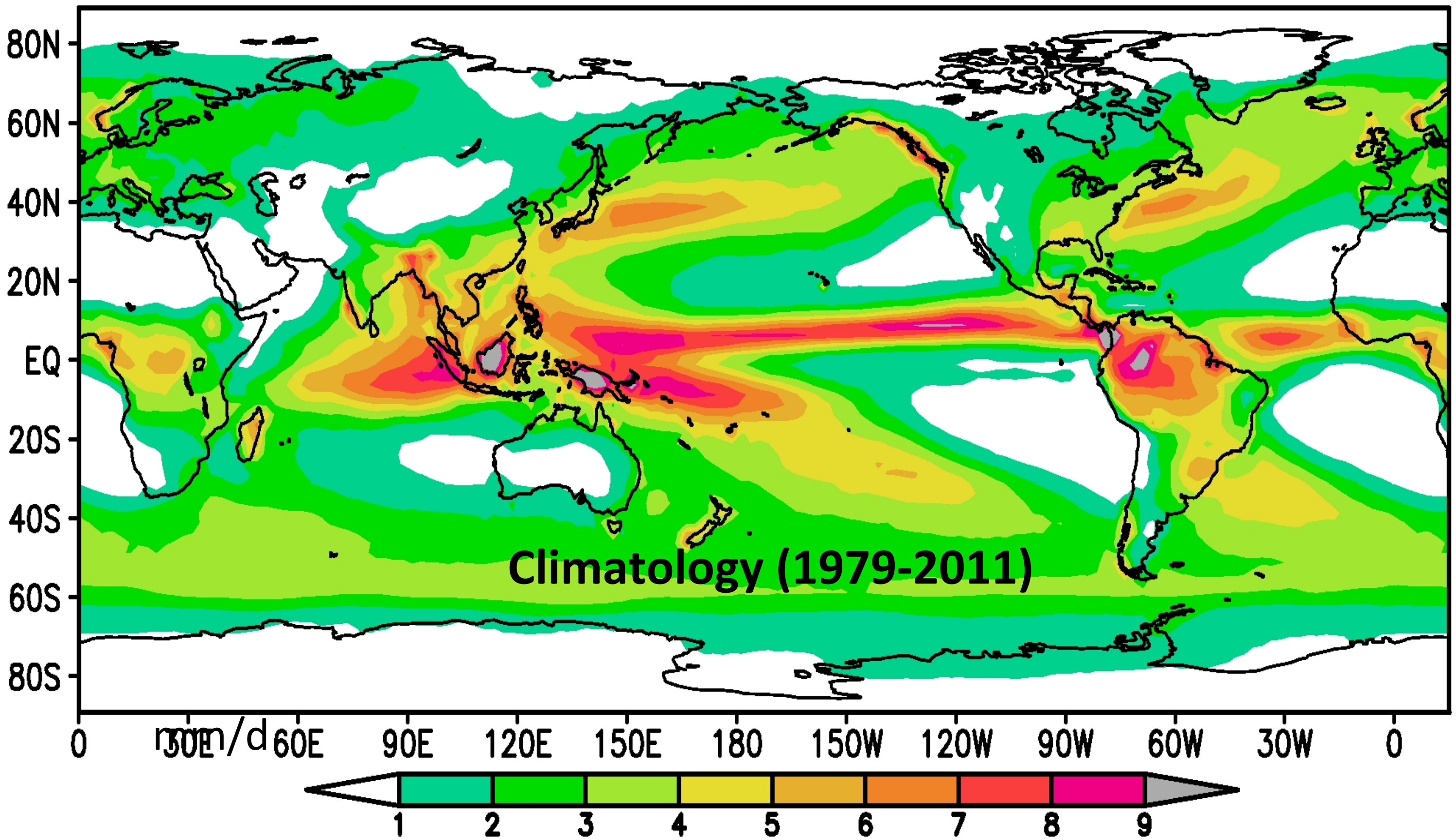
GPCP: Global Precipitation Climatology Project, a WCRP/GEWEX Project



GPCP data used in > 1500 journal articles

GPCP Global Precipitation Analysis

UMD, NASA, NOAA, DWD, GMU, others

Monthly, 2.5° Merged Analysis (1979-present) Version 2.2

Adler et al. (2003), J. Hydromet; Huffman et al. (2009) GRL

Version 2.2 being "transferred to operations" at NOAA NCDC (Asheville);

Version 3 of GPCP products under development (NASA MEASURES)

- GPCP monthly is an analysis based on various satellite data sets and a gauge data set
- Over ocean (in tropics and mid-latitudes) it uses SSMI (now SSMIS) rain rates (Chiu/Chang/Wilheit) to adjust geo-IR estimates for sampling (mean values are driven by microwave estimates)
- Over land (in tropics and mid-latitudes) Ferraro SSMI algorithm is used to adjust IR
- Over higher latitude ocean and land a TOVS/AIRS empirical approach (Susskind) is used
- Gauge analysis (GPCC/DWD) is used over land in combination with merged satellite estimates (mean values follow gauge analysis [adjusted for wind loss])
- Final merger technique by Adler/Huffman in references (uses error-weighted blending where appropriate)
- Pre-1988 period uses OLR Precipitation Index (Xie) for satellite estimates, cross adjusted with later microwave period

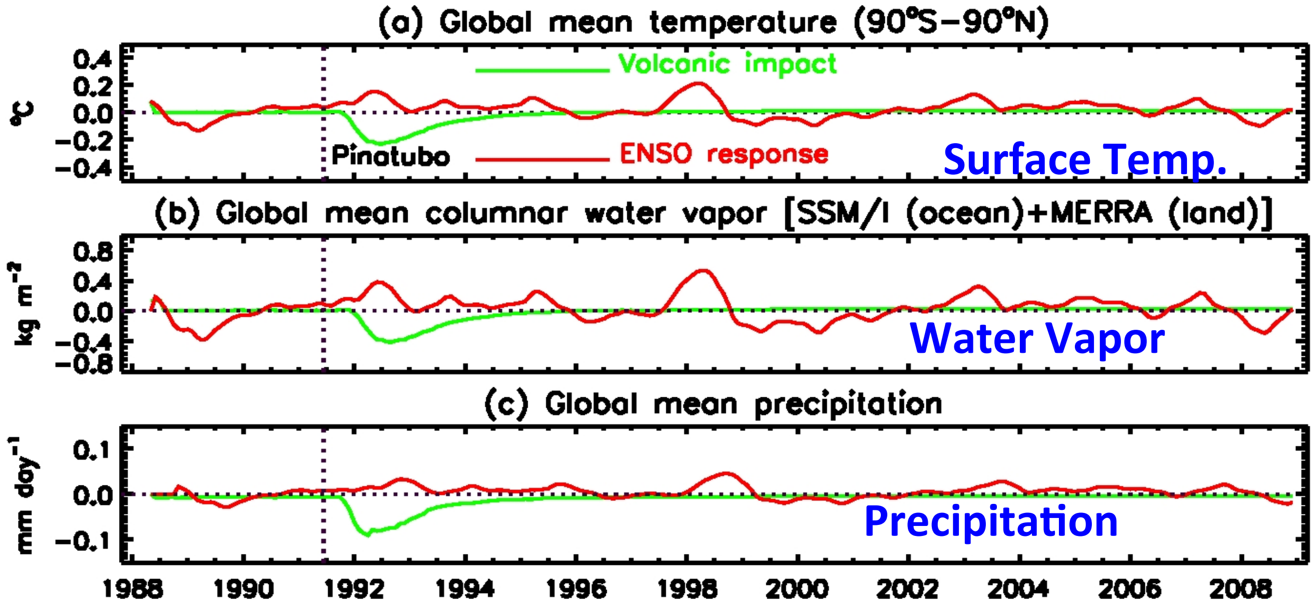
Global Changes (1988-2008)

Inter-annual (ENSO and Volcano)

Surface Temp. (Amplitude ~ .2C)

Water Vapor (~ 7%/C for ENSO, ~6%/C for volcano)

Precipitation (~ 2%/C for ENSO, ~4%/C for volcano)



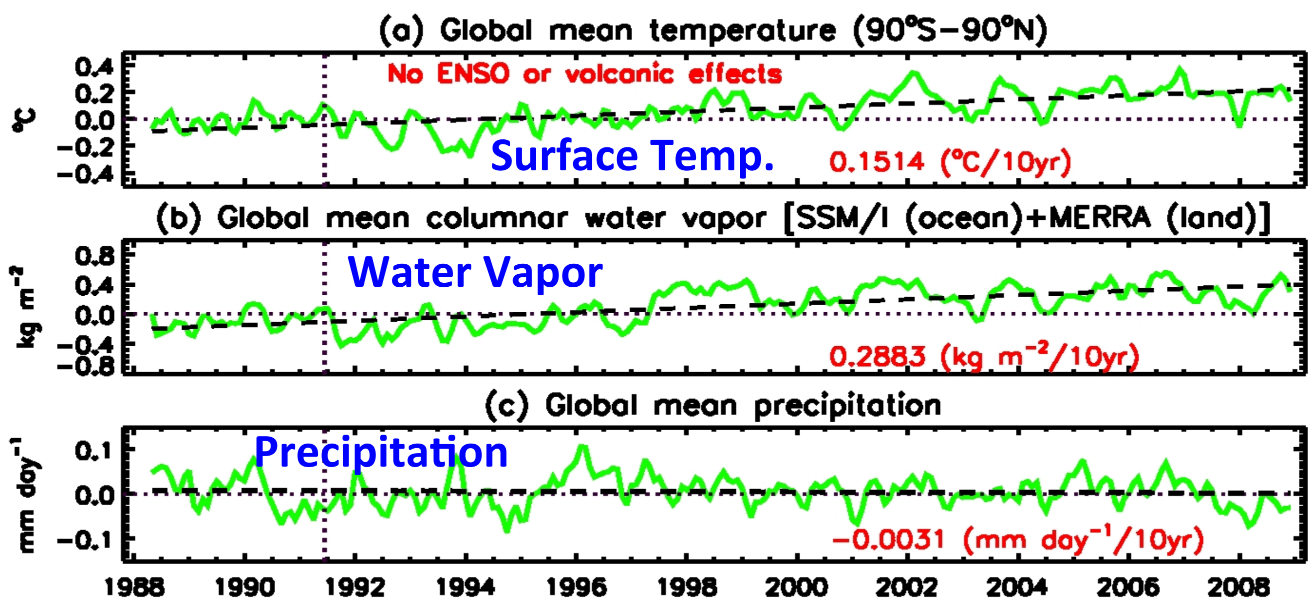
Trends

Surface Temp. (.15 C/ 10yr)

Water Vapor (~ 7%/C, taking into account MERRA trend bias)

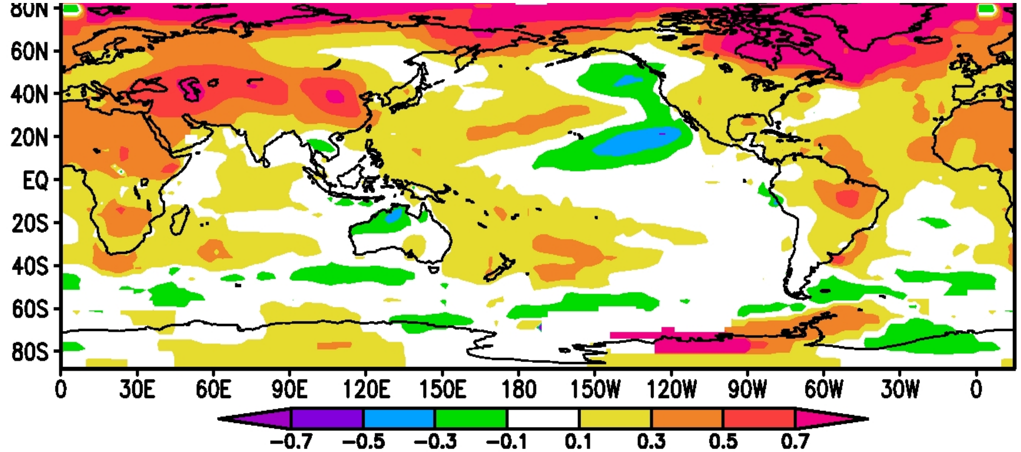
Precipitation (~ 0%/C)

Gu and Adler 2011 Int.J.Clim.



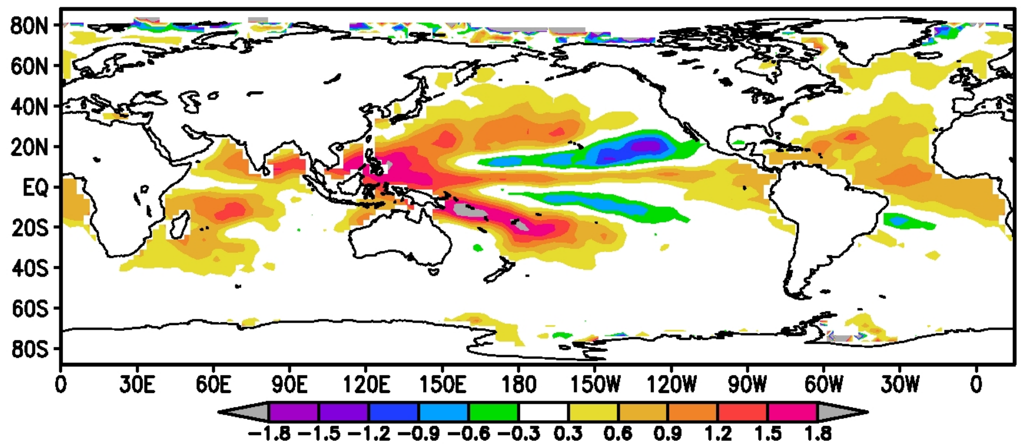
Patterns of Trends

(1988-2008)



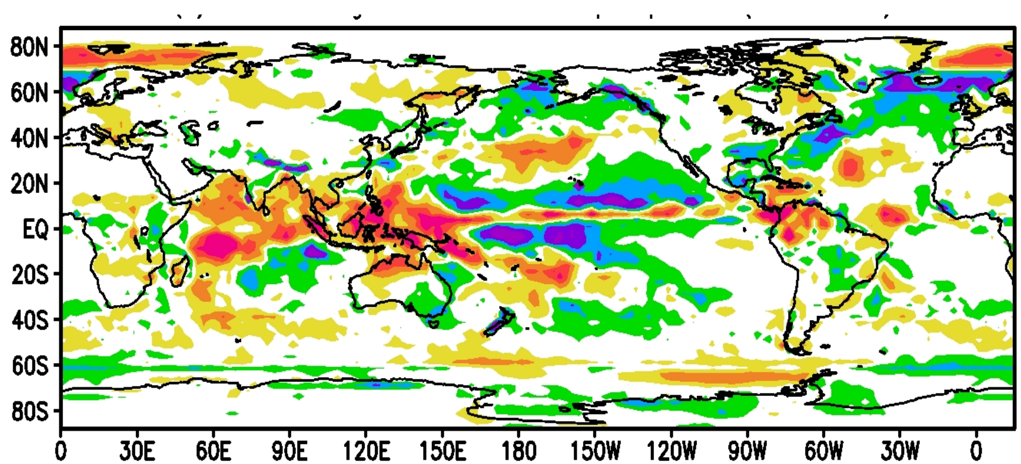
Surface Temperature from GISS

°C/decade



Water Vapor from SSMI (ocean)

mm/decade



Precipitation from GPCP

mm/d/decade

Bias Error Estimates for GPCP Monthly Analysis

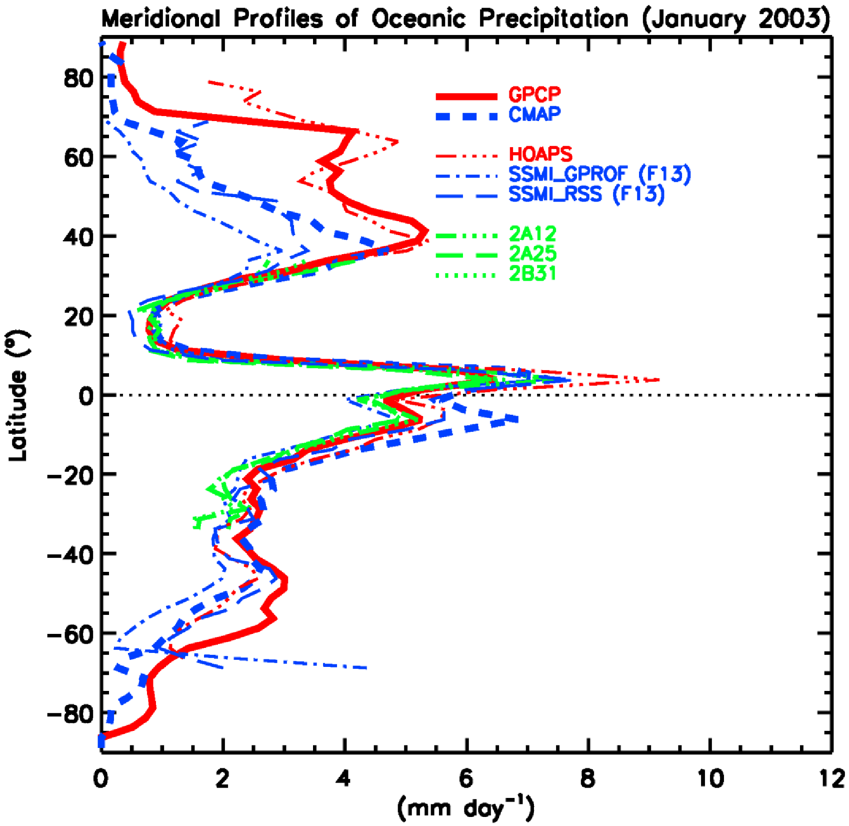
Outline of Method for Bias Error Calculation

Adler et al., 2012 (JAMC)

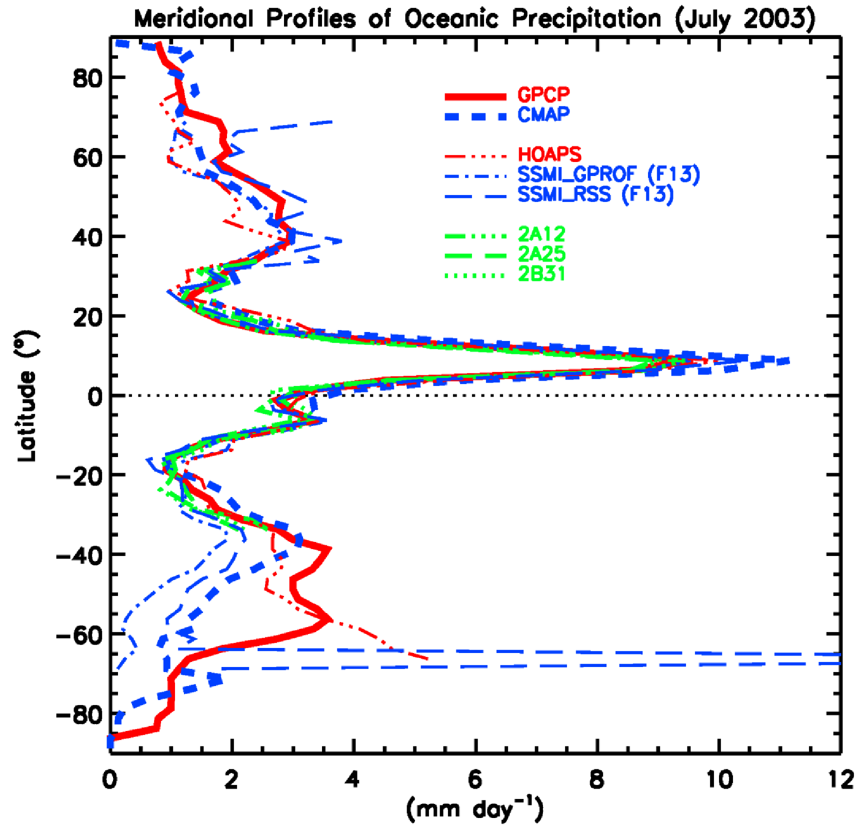
- Potential input products: GPCP, CMAP, GPROF (ocean), RSS (ocean), HOAPS (ocean), TRMM [PMW(ocean), Radar (land & ocean), Combined (land & ocean)].
- Selection of products to be included uses a zonal mean test (land and ocean separate) on individual months
- ***GPCP is used as "first guess"; only products with zonal means (for individual months, ocean and land separately) +/- 50% of GPCP are included in remainder of analysis***
- Composite mean is computed and dispersion of products (equate to bias error estimate) is σ among products; assign to GPCP

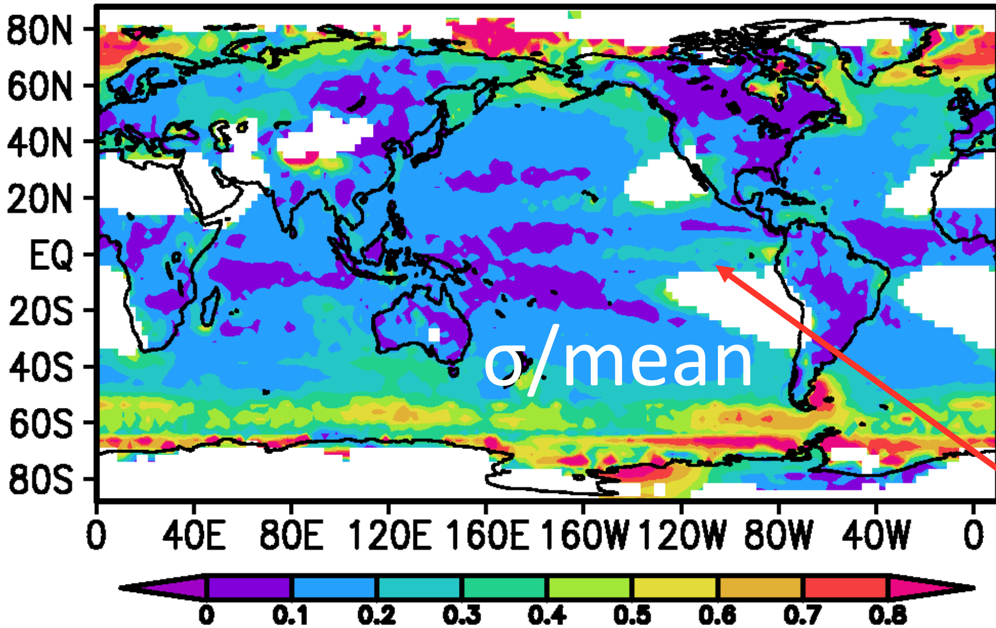
Zonal Mean Inputs (Ocean) for Individual Months

January 2003



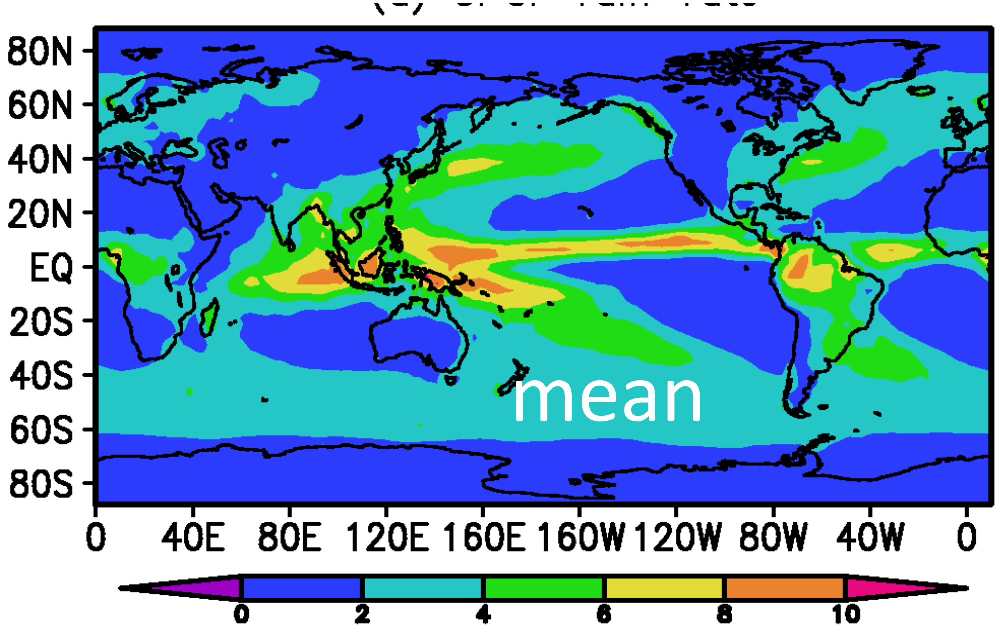
July 2003





<u>Bias</u> <u>Errors</u> for GPCP Climatology

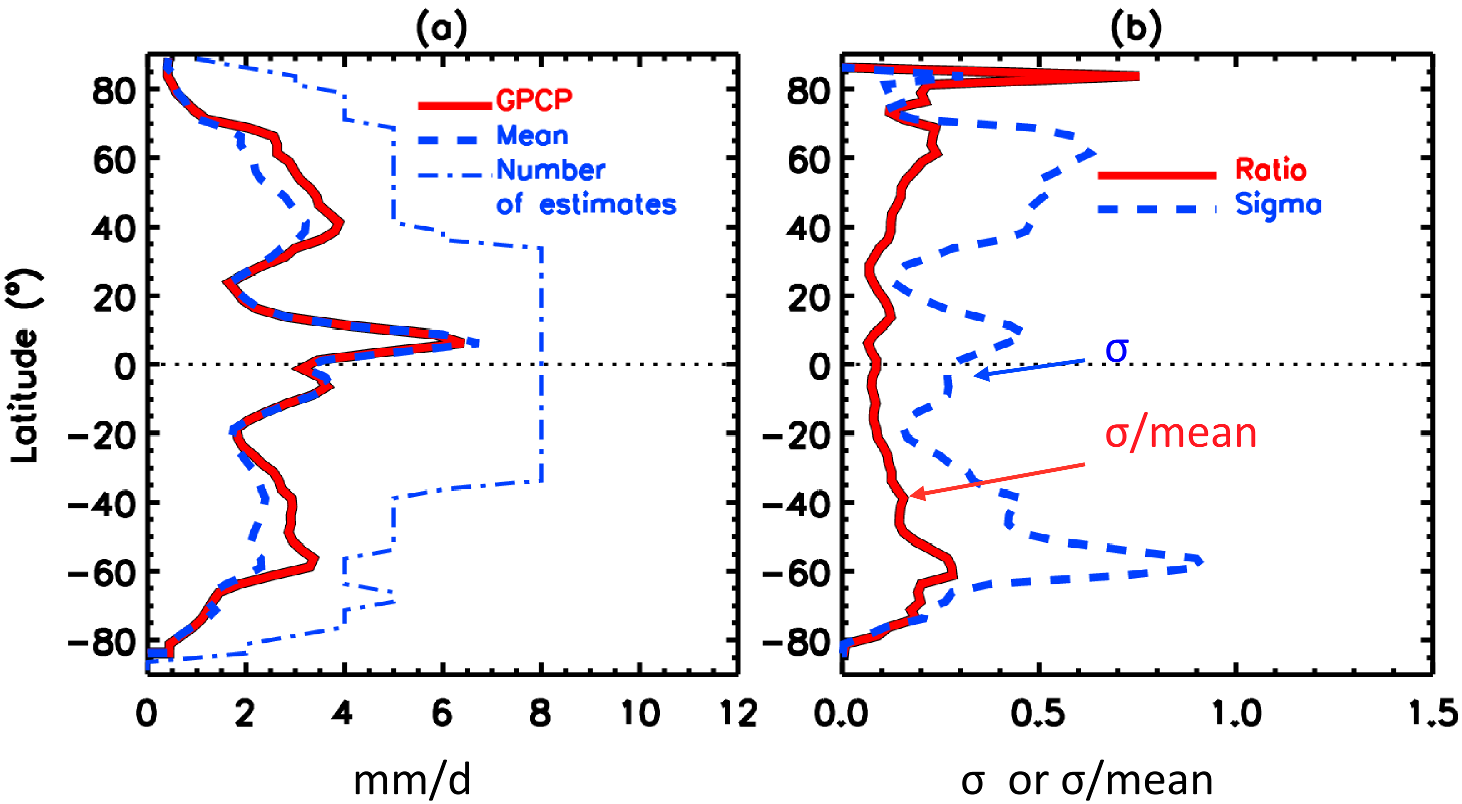
Higher percentage errors in E. Pacific, higher latitudes and over mountains



Results for 10 year "Climatology"--entire seasonal cycle

Adler et al., 2012 (JAMC)

Zonal Means (Ocean)



σ here is σ of zonal means , not zonal mean of σ's.

σ higher in mid-latitude for same rain rate; *i.e.*, % bias error larger in mid-latitude (~ 15% at 40º vs. ~10% at 0-15º)

Estimate of Bias Error in Global Precipitation Totals

	Rain Rate mm/d	σ (bias error) mm/d	σ/mean (%)	
Land + Ocean	2.6	0.25	9%	
Land	2.1	0.16	8%	
Ocean	2.9	0.29	10%	

[These error estimates are <u>upper bounds</u> due to regional averaging of errors and inclusion of still questionable input estimates]

Adjustment for above gives about +/- 7% for estimated bias errors

An Application of of the Bias Error Estimates

Mean Global Precipitation Estimates Used in Water and Energy Balance Studies

GPCP analyses are often used as a standard or starting point for discussions

-- current GPCP global long-term number is 2.68 mm/d with an estimated error bar of ~ +/- 7% (Adler et al. 2012 JAMC)

-- in order to balance global water and/or energy cycle some researchers modify GPCP number (and other budget component values) to achieve balance, e.g.,

--Trenberth et al. (2009) increase global GPCP number by 5% (within estimated error range)

--Stephens et al. (2012) increase global GPCP number by 15% to achieve balance (unfortunately based on incorrect assumptions about GPCP)

nature geoscience

PROGRESS ARTICLE

PUBLISHED ONLINE: 23 SEPTEMBER 2012 | DOI: 10.1038/NGEO1580

An update on Earth's energy balance in light of the latest global observations

Graeme L. Stephens[1*], Juilin Li[1], Martin Wild[2], Carol Anne Clayson[3], Norman Loeb[4], Seiji Kato[4], Tristan L'Ecuyer[5], Paul W. Stackhouse Jr[4], Matthew Lebsock[1] and Timothy Andrews[6]

Climate change is governed by changes to the global energy balance. At the top of the atmosphere, this balance is monitored globally by satellite sensors that provide measurements of energy flowing to and from Earth. By contrast, observations at the surface are limited mostly to land areas. As a result, the global balance of energy fluxes within the atmosphere or at Earth's surface cannot be derived directly from measured fluxes, and is therefore uncertain. This lack of precise knowledge of surface energy fluxes profoundly affects our ability to understand how Earth's climate responds to increasing concentrations of greenhouse gases. In light of compilations of up-to-date surface and satellite data, the surface energy balance needs to be revised. Specifically, the longwave radiation received at the surface is estimated to be significantly larger, by between 10 and 17 Wm^{-2}, than earlier model-based estimates. Moreover, the latest satellite observations of global precipitation indicate that more precipitation is generated than previously thought. This additional precipitation is sustained by more energy leaving the surface by evaporation — that is, in the form of latent heat flux — and thereby offsets much of the increase in longwave flux to the surface.

"the latest satellite observations of global precipitation indicate that more precipitation is generated than previously thought."

So, what is the state of knowledge of mean global (or regional) precipitation?

From Stephens et al. paper

“There are **at least two reasons why past estimates of global latent heat flux deduced from global precipitation should be increased.**

(1) The remote-sensing methods widely used to estimate precipitation, especially over the vast oceans, **have documented biases that imply that the amount of precipitation is underestimated** [49–52].

New global precipitation **information from the CloudSat rad**ar suggests that precipitation has been **underestimated by approximately 10% over tropical ocean regions** [49] and **by even larger fractions over mid-latitude oceans** [51–53].

(2) The **total contribution from snowfall to the global precipitation** is also not precisely known and has been excluded from previous global latent heat flux estimates. Based on new estimates of global snowfall [54], we estimate the contribution to the total global latent heating is approximately 4 Wm–2 (Supplementary Information).

For these reasons, the value of latent heat flux stated in Fig. B1 has been **increased by 4 Wm–2 over the Global Precipitation Climatology Project [49] estimate of 76 Wm–2 and then increased by 10% (8 Wm–2).**”

Therefore, Stephens et al. increases GPCP global precip. number by ~ 5% for snow and then ~10% for general underestimation reasons (total about 15%).

Issues with Stephens et al. in Relation to GPCP Global Precipitation Number

- **Snow over land**—Included explicitly in GPCP over land through use of gauges estimating for wind loss based on GPCC climatological (month of the year) adjustments. Lately GPCC says adjustments may be a little high for wintertime conditions. *[recent GPCP version is somewhat larger (rain + snow) over land due to improved gauge analysis over mountainous regions—could still be low in these regions—about 1% problem globally]*

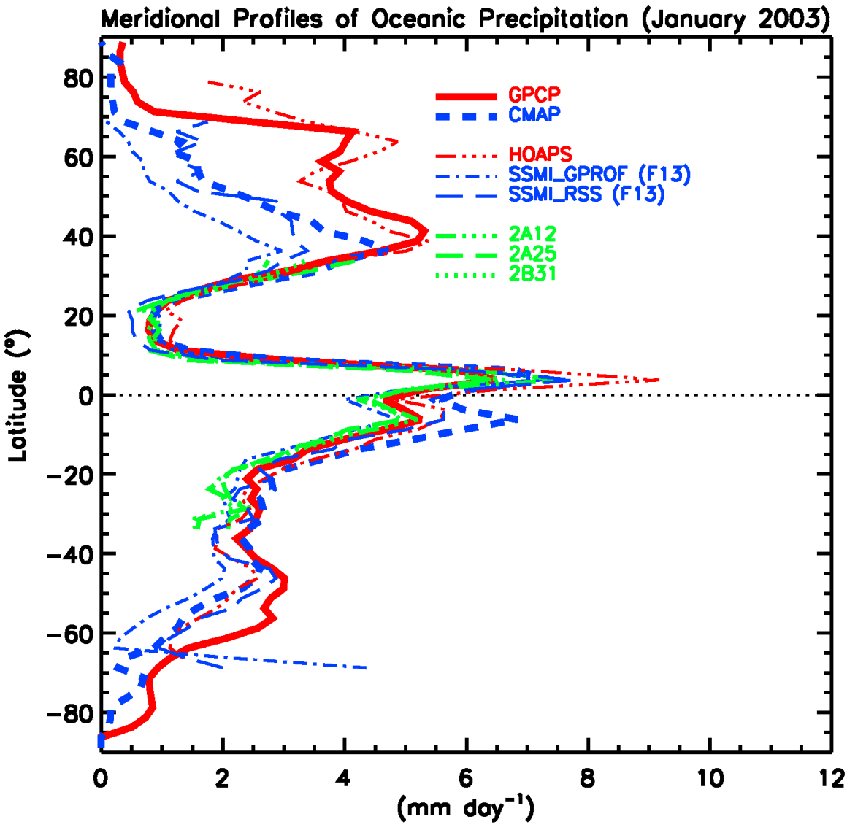
- **Snow over ocean**—Included implicitly over ocean through TOVS/AIRS empirical technique using wind-loss adjusted gauge information over land—relations transplanted to ocean

- **Underestimation over middle/high latitude oceans**—Passive microwave (PMW) estimates traditionally too low over middle/high latitude ocean. GPCP (Adler/Huffman) understood that 15 years ago, so developed analysis to give more accurate absolute value.

- **Underestimation over tropical oceans**—see TRMM and TRMM + Cloudsat

Zonal Mean Inputs (Ocean) for Individual Months

January 2003



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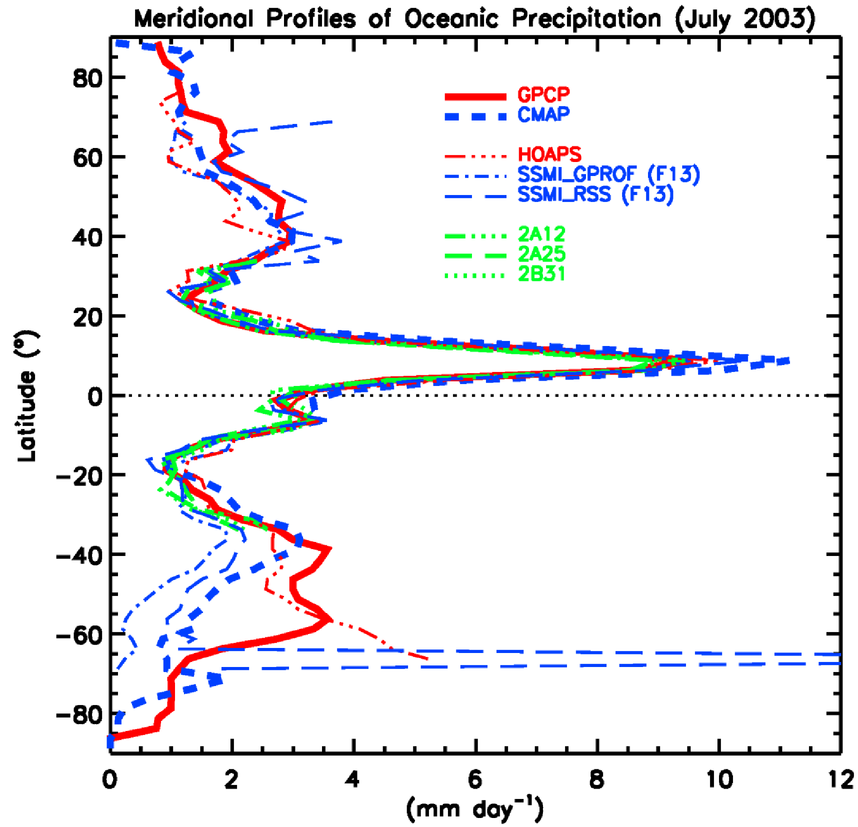


TRMM Composite Climatology (TCC)

Adler et al., 2009 (JMSJ); Wang et al., 2013 (in prep.)

Selected TRMM Rain Products for [using V7]

<u>Ocean and Land:</u>

1) TMI (2A12) *

2) PR (2A25) Near Surface

—adjusted for orbit boost in 2001 (by

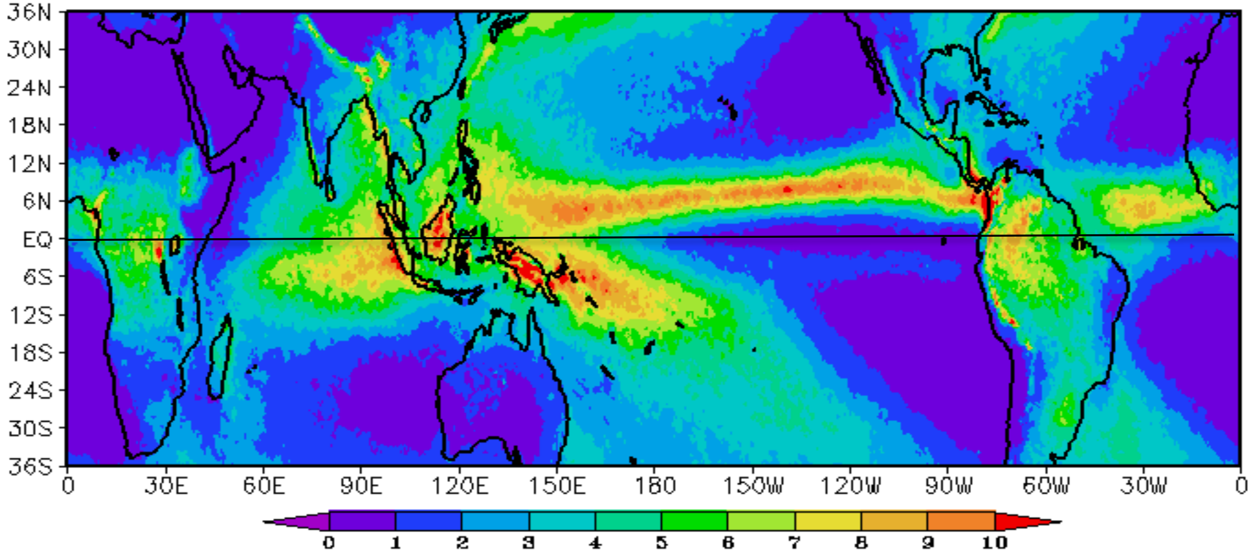
5.4% based on Shimizu et al. (2009)

3) Combined (2B31)

*** <u>Previous version used 3B43</u> (multi-satellite/gauge product) instead of 2A12 over land**

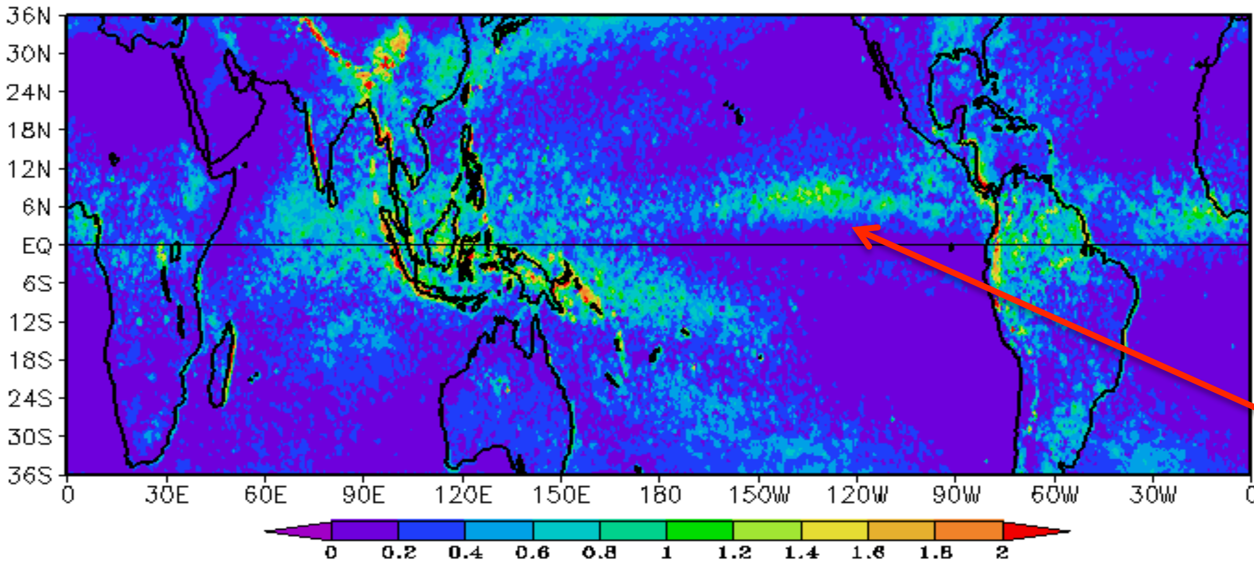
<u>significant quality control over land is required</u> for use with Version 7 2A12

Thirteen-year (1998-2010) TRMM Composite Climatology (TCC)



TRMM Composite Climatology of Surface Rainfall (1998-2010)

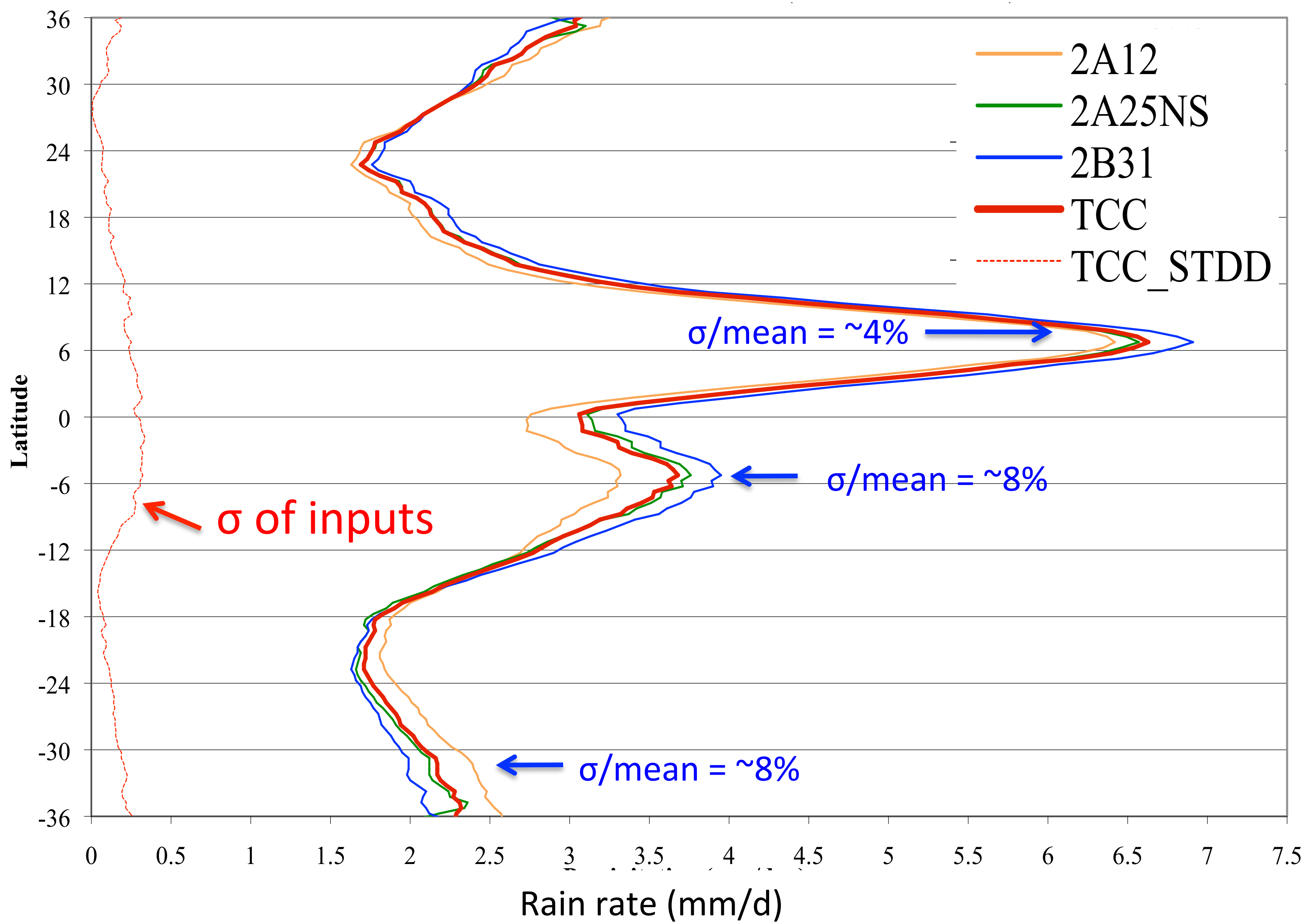
Climatological value is mean of three input products on 0.5 lat./long. grid



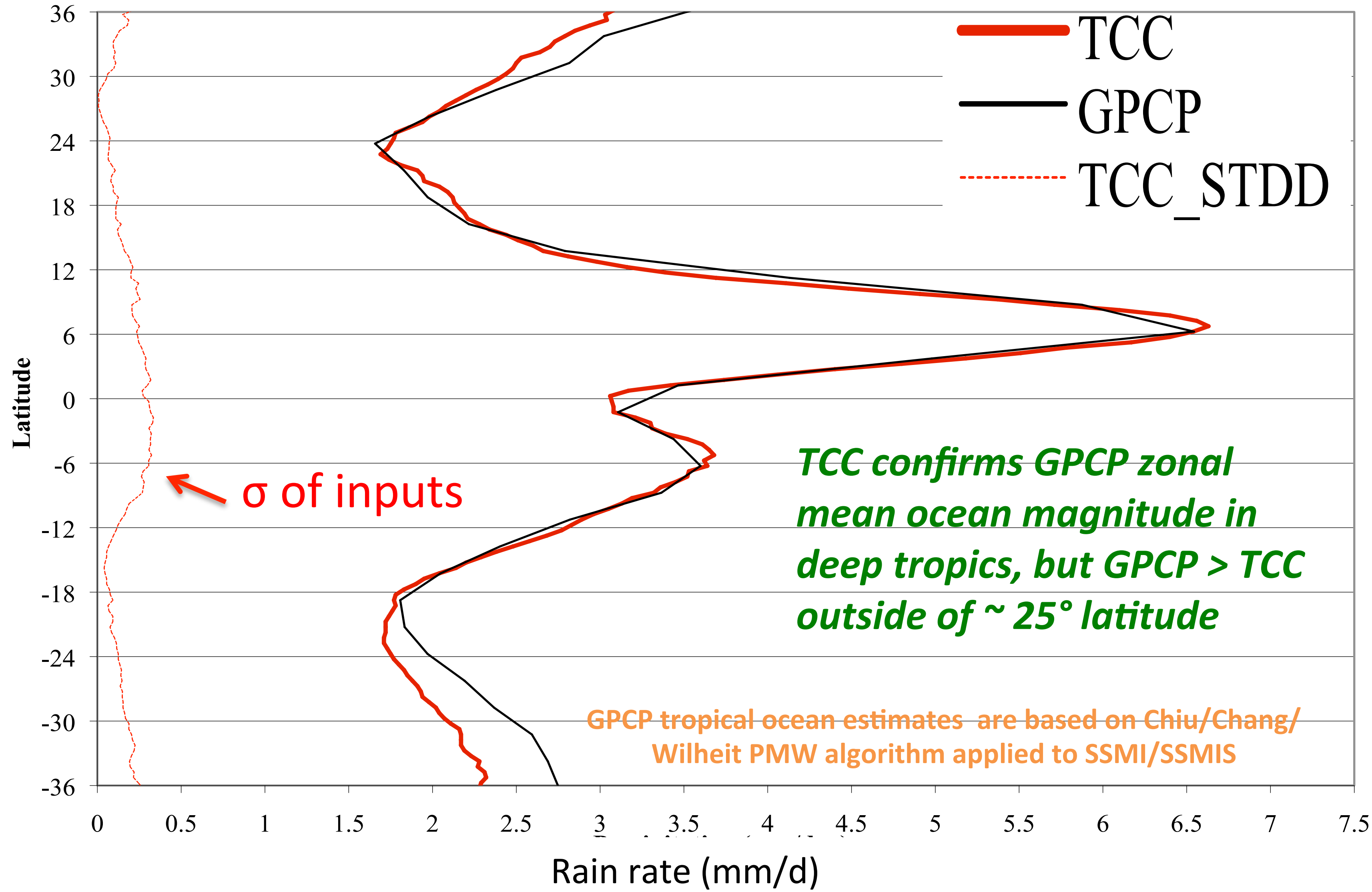
Standard Deviation of the TCC Inputs (1998-2010)

Standard deviation (σ) among the three products is an estimate of error—note E. Pac. peak values (σ/mean= 1.3/9 = 14%)

Zonal Mean Ocean Rain Rate (TCC and the Three Inputs)



Zonal Mean Ocean Rain Rate (TCC and GPCP)



Tropics (25N-25S) Precipitation

		Total	Ocean	Land
25°S–25°N	2A12	2.95	3.02	2.89
	2A12QC	2.88	2.98	2.59
	2A25-NS	3.12	3.21	2.85
	2B31	3.23	3.34	2.91
	TRMM Composite	3.08	3.18	2.79
	GPCP	3.21	3.12	3.48

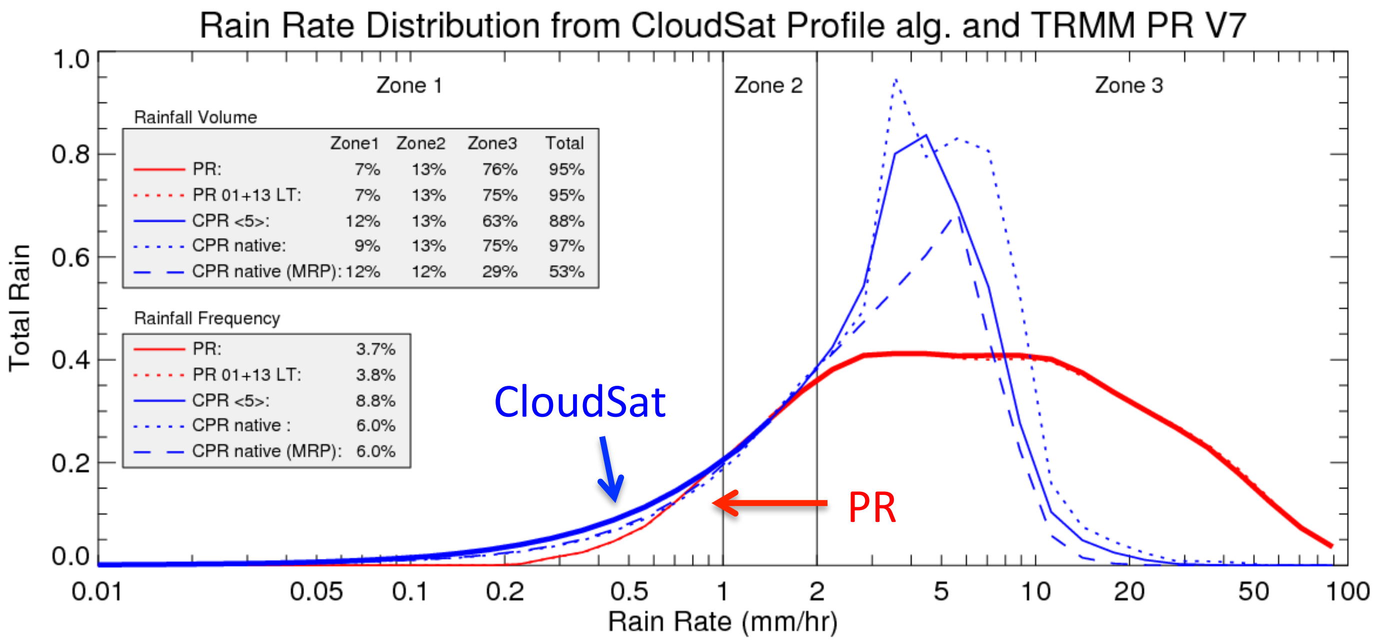
TCC (Ocean) = 3.18 mm/d +/- 6%

(σ/mean = 0.19/3.18 = ~ 6%)

Bias Error Estimate may be an underestimate due to lack of independence among estimates

PR and CloudSat Rain Rate Distributions ("missing" light rain in tropics)

Berg, L'Ecuyer, Haynes (2010, JAMC) [updated]



PR (post-boost) has ~5% less light rain (by volume) than CloudSat (Berg et al. [updated])

PR (pre-boost) has ~ 5% more rain than PR (post-boost) (Shimizu et al.)

TCC adjusts PR (post-boost) by 5.4% based on Shimizu et al. so therefore indirectly has taken care of "missing" light rain. There still must be some light rain missed by PR, but perhaps only a 1-2% problem in deep tropics.

Tropical Mean (Ocean) Rainfall Estimates

mm/d	TRMM Radar (2A25 NS--adjusted)	TRMM Composite Climatology (TCC)*	GPCP	TRMM PR + CloudSat**
35N-35S (ocean)	2.9	2.9	2.9	3.0 (3 years)
25N-25S (ocean)	3.2	3.2	3.1	

There seems to be a remote sensing consensus emerging of the mean magnitude of tropical ocean rain—this doesn't mean that this is the correct answer, but that current remote sensing information (TRMM and CloudSat) does not lead to significant "missed rain" in the tropics as claimed by a few.

*Adler et al. 2009 JMSJ

**Behrangi et al. 2012 JGR

Global Mean (Ocean) Rainfall Estimates

mm/d	GPCP	PR + CloudSat; AMSR + CloudSat*	Trenberth GPCP + 5%
60N-60S (ocean)	3.03	3.05*	
Global ocean	2.89		3.06

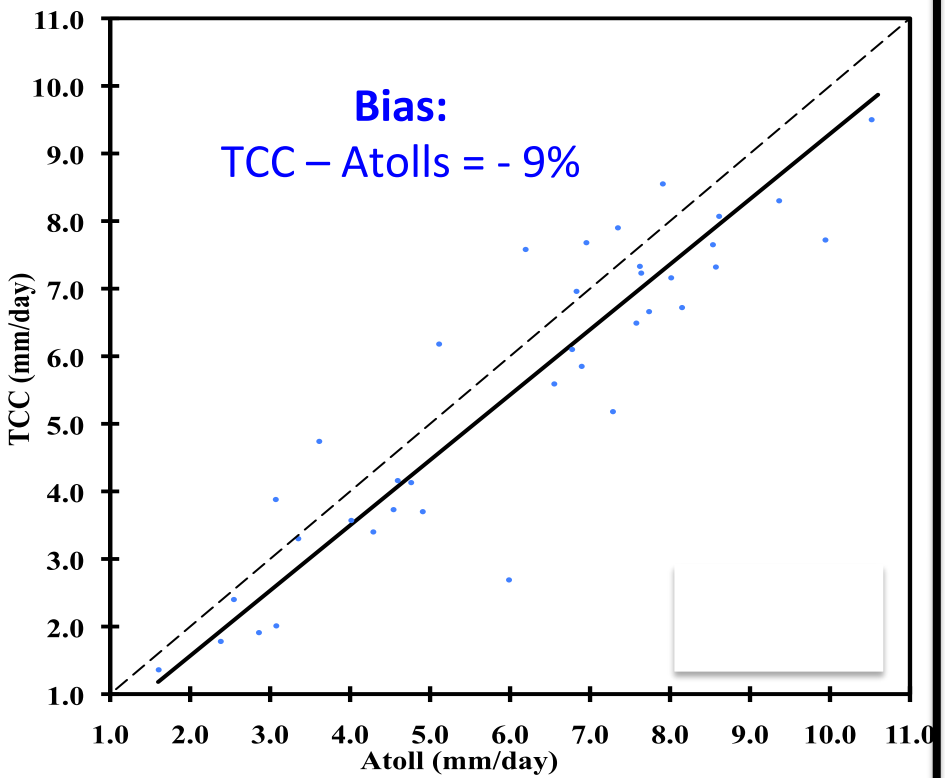
*Behrangi et al. 2012 JGR

.GPCP global ocean number still seems reasonable, but needs to be examined again with improved data (e.g., GPM, etc.)

GPCP uses TOVS/AIRS-based empirical estimates in higher latitudes

Tropical Ocean Validation (or Comparison)

TCC vs. Atolls (13-year mean)



Atolls are probably not representative of open ocean—atoll itself increases convection—but by how much?

2A25 NS (V7) vs. Kwajalein radar/gauge

Adapted Wolff/Marks results with PR adjusted upward by 5.4% (for boost) for 2008 and 2009.

Bias results are:

PR - KWAJ = + 7.9% (2008)
+ 1.6% (2009)
~ + 5%

After a lot of great work with Kwajalein radar, with buoys, etc. I still think <u>we do not have a tropical ocean validation standard</u> to judge tropical ocean absolute rain magnitude

Summary and Conclusions

- GPCP is a widely used global precipitation analysis based on satellite and gauge data sets. The Stephens et al. description of limitations and inaccuracies in GPCP absolute value is inaccurate.
- The GPCP global total estimate is ~ 2.6 mm/d +/- 7% (Adler et al., 2012), putting the Stephens (let's just add 15% to GPCP) number at about 2σ—possible, but unlikely.
- TRMM climatology (Adler et al., 2009) confirms GPCP in deep tropics, with GPCP being a little bigger in sub-tropics.
- TRMM plus Cloudsat radars do not indicate any significant "missing rain" in tropics and again confirms GPCP tropical total rainfall (Berg/L'Ecuyer, Behrangi et al., 2012)
- TRMM plus Cloudsat in tropics and AMSR plus Cloudsat in extratropics leads to global ocean total precipitation nearly identical with GPCP analysis value (Behrangi et al., 2012)
- Global water and energy budget closures require continued **careful** analysis and improvement of retrievals and analyses. If there are faults in the global precipitation estimations (e.g., underestimation) it probably doesn't have to do with light rain or snow, but perhaps with intense convective rainfall. GPM will help, but signal attenuation still an issue